

## REASONABLE ASSURANCE AND IN-SITU TESTING

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### ABSTRACT

The Department of Energy is currently preparing site characterization plans for sites being considered for the first geologic repository. The site investigations described in these plans will be aimed at providing "reasonable assurance" to the Nuclear Regulatory Commission that the performance objectives and criteria specified in 10 CFR Part 60 will be met. The in-situ testing being planned by the DOE for site characterization, and the subsequent testing conducted as part of performance confirmation, reflects how the basis for "reasonable assurance" will change through the licensing process.

The Department of Energy (DOE) is currently preparing site characterization plans for sites being considered for the first geologic repository. These plans will describe the site investigations that will be conducted to obtain the information necessary for a license from the Nuclear Regulatory Commission (NRC) under 10 CFR Part 60. As part of these investigations, the DOE will conduct in-situ testing at the depth and the location of the potential repository. In planning the in-situ testing program, the DOE will make a judgment as to how much information is enough for the NRC to grant a construction authorization. The NRC must be able to determine that there is "reasonable assurance" that the performance objectives and criteria specified in 10 CFR Part 60 for the repository system will be met. This paper discusses the DOE's position on how the basis for the finding of "reasonable assurance" at the time of construction authorization will differ with those associated with the later stages of repository development.

### STAGES IN THE LICENSING PROCESS

The licensing of a geologic repository will consist of several stages, as described in 10 CFR Part 60. After selecting a site, the DOE will submit a license application to the NRC, according to the requirements of Section 60.21. After reviewing the application and upon making the findings required by Section 60.31, the NRC will authorize the DOE to construct the repository, and the DOE will proceed with repository construction, to the point of being prepared to accept waste for emplacement. The DOE will then update the license application, incorporating information obtained during construction. The NRC will review the updated application and, upon making the findings required by Section 60.41, will issue a license to receive and possess the waste. After filling the repository with waste and completing the required performance confirmation program, the DOE will submit an application to amend the license for permanent closure.

At each of these four licensing stages (construction authorization, license to receive and possess the waste, and license amendment for permanent closure and license termination), which

together may span more than 50 years, the NRC will determine whether there is reasonable assurance that the health and safety of the public will be adequately protected. (To authorize construction, the NRC must also make findings about common defense and security as well as environmental matters, but such matters are not discussed here.) As explained below, the nature of the licensing process implies that the basis for the finding associated with reasonable assurance will have different levels of confidence at each stage.

### DEFINITION OF REASONABLE ASSURANCE

A specific definition of what constitutes reasonable assurance is not provided in 10 CFR Part 60. In supplementary information to the final rule, the NRC<sup>1</sup> noted that "the reasonable assurance standard is derived from the finding the Commission is required to make under the Atomic Energy Act that the licensed activity provide 'adequate protection' to the health and safety of the public; [it] allows flexibility necessary for the Commission to make judgmental distinctions with respect to quantitative data which may have large uncertainties (in the mathematical sense) associated with it." A critical consideration in making this finding will be the compliance of the repository site and design with the performance objectives and criteria contained in Subpart E of 10 CFR Part 60 and the EPA standards in 40 CFR Part 191. For the license application, compliance with the NRC criteria and EPA standards will be demonstrated by a performance assessment of the entire repository system--the site, the repository itself, and the waste package. This assessment will use computer models and data from site characterization to evaluate the performance of the repository under both expected conditions as well as potentially disruptive conditions that, though unexpected, are sufficiently credible to warrant investigation. To account for uncertainties in the data from the site or in the understanding of the repository's performance, conservative assumptions will be used.

The NRC<sup>2</sup> draws a distinction between the "standard of performance," which can be readily expressed in quantitative terms, and the "quality of evidence," which is not as easily

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quantifiable. The required standard of performance consists of the performance objectives and other technical criteria of Part 60. The required quality of evidence is not described in Part 60 and has not yet been defined. These two aspects of reasonable assurance, illustrated in Fig. 1, are explained further<sup>3</sup> as the "two principal" elements that will go into the NRC's application of the reasonable assurance concept. The NRC must be satisfied that the performance assessment is sufficiently conservative, and its limitations are sufficiently well understood, to provide assurance that the actual performance of the repository will be within predicted limits." In this regard, the NRC believes that judgments about such things as the correctness of models cannot be quantified and that confidence must be characterized in the subjective term of "reasonable assurance." This subjective, or qualitative, aspect of the quality of evidence is the key aspect of reasonable assurance that will change with each stage in the licensing process.

While the NRC has attempted to define how reasonable assurance will be used in the licensing process, it has not explained how the finding associated with reasonable assurance will be defined during the various phases of the process--that is, whether the required level of assurance will change during the licensing process. Furthermore, a recent NRC staff paper<sup>4</sup> suggests that the NRC staff may view reasonable assurance as a fixed standard that does not change after the initial license application. The DOE, on the other hand, considers that, since the uncertainties associated with repository performance will change through the licensing process, it follows that the required level of assurance will also change.

The concept that the confidence levels associated with reasonable assurance will change in time has been recognized by others as well (e.g., Ref. 6), but it needs to be addressed in more specific terms. To explore further how assurance levels should change with time, it is useful to define the different types of uncertainties associated with the repository and to understand how these uncertainties will change during the development of the repository.

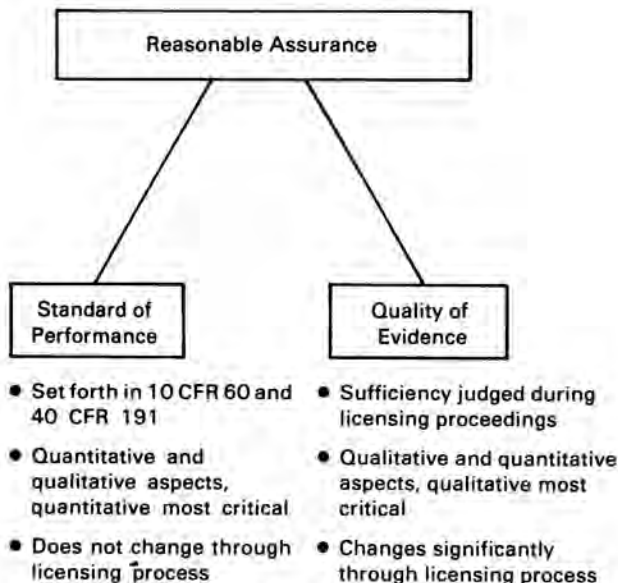


Fig. 1. Components of Reasonable Assurance.

It is recognized by the technical community that the uncertainties associated with repository performance cannot be completely eliminated and that these uncertainties are unprecedented because of the time, scale, and physical phenomena relevant to a geologic repository. Although their range will be reduced, these uncertainties will remain even in the late stages of the licensing process.

These uncertainties are recognized by the EPA and the NRC regulations governing geologic repositories (40 CFR Part 191 and 10 CFR Part 60, respectively). The NRC's 10 CFR Part 60 refers to the "greater uncertainties" (60.101) that are associated with repository performance, and indeed the NRC staff has pointed out<sup>4</sup> that "the licensing finding must be made in the face of substantial uncertainties about performance of the repository system over very long periods of time." The EPA's 40 CFR Part 191 acknowledges the "substantial uncertainties" (191.13) and even suggests that, in view of the uncertainties involved in predicting performance over 10,000 years, the term "reasonable expectation" is preferable to "reasonable assurance."

These substantial uncertainties are the reason the quality of evidence will play an important role in determining that there is reasonable assurance about the performance of the repository. There are three types of uncertainties that are involved in the quality of evidence for reasonable assurance<sup>6</sup>:

1. The natural variability of site characteristics. This uncertainty results from not being able to measure the characteristics at all locations within the site.
2. The correctness of measured values for site characteristics and performance. This uncertainty results from inherent limitations in the techniques used to measure properties and phenomena and in errors in the application of those techniques.
3. The correctness of models for predicting performance. This uncertainty is due to the simplifications necessary in modeling and incomplete knowledge of the applicability of the model with respect to the scale and duration of the phenomenon being modeled.

The quality of evidence has quantitative as well as qualitative aspects; both will change with time in the licensing process. In evaluating the quality of evidence at any given time, it is necessary to consider the above uncertainties both quantitatively and qualitatively; examples of questions to be asked in these evaluations are given in Table I. The quantitative questions are relatively straightforward; the qualitative questions are more difficult to answer and involve considerable subjective judgment. For example, how will it be decided that a sufficient number of measurements of a particular parameter have been made? While there are statistical tests for the adequacy of sampling programs, such tests are not sufficient in themselves. Judgment by experts will be made, by using their experience and knowledge to weigh the available evidence. This available evidence will be substantially different at different stages of the licensing process. In particular, the questions

TABLE I

Examples of Questions To Be Answered in the Evaluation of the "Quality of Evidence" Relative to Reasonable Assurance

Type of Uncertainties	Quantitative Evaluation	Qualitative Evaluation
1. Natural spatial variation of site characteristics	<ul style="list-style-type: none"> <li>What are the statistical parameters describing distribution of characteristics (e.g., mean, standard deviation)?</li> <li>What is the spatial distribution of characteristics?</li> </ul>	<ul style="list-style-type: none"> <li>Have a sufficient number of measurements been made?</li> <li>Have measurements been made at the right locations?</li> </ul>
2. Correctness of measured values for site characteristics	<ul style="list-style-type: none"> <li>What is the inherent potential error in the measurement techniques?</li> </ul>	<ul style="list-style-type: none"> <li>Were the appropriate measurement and analysis techniques used?</li> <li>Were the proper procedures followed in making the measurements?</li> </ul>
3. Correctness of models for predicting performance	<ul style="list-style-type: none"> <li>How do site characteristics change with time and other influences?</li> <li>What is the difference between the performance predicted by models and that observed in testing?</li> <li>Are the models verified?</li> <li>Are the models validated?</li> </ul>	<ul style="list-style-type: none"> <li>Were the models validated under representative conditions?</li> </ul>

pertinent to the first and the third group of uncertainties will be answered with substantially increasing evidence (and increasing confidence) as licensing proceeds. Substantially more data will be available about site characteristics and substantially more information available will be from testing and monitoring to validate models. How the quality of evidence increases as licensing proceeds can be illustrated by describing the in-situ testing program and what is known and what is not known during the licensing process.

IN-SITU TESTING PROGRAM

Site characterization will be the first major step in expanding the available evidence and reducing the uncertainties associated with repository performance. The site characterization program will be conducted in accordance with a plan that is mandated by the Nuclear Waste Policy Act and whose scope is defined by the NRC in a regulatory guide. It will be based on a performance allocation for the various subsystems, components, and elements of the repository system. The performance allocation, which will be implemented in close interaction with the NRC, is a prerequisite to establishing the necessary and sufficient level of testing.

The DOE's plans for site characterization include surface-based boreholes and tests, the drilling of two exploratory shafts to the depth of the repository, and the construction of an exploratory-shaft facility (ESF). Consisting of more than 5000 feet of excavation, this facility will be used for various tests. (A smaller facility, with up to 1000 feet of excavation, was deemed sufficient by the NRC. See 46FR13971, the statements of consideration for licensing procedures in 10 CFR Part 60.) The layout of the facility and its relationship to the underground excavations for the repository are shown in Fig. 2.

At the second licensing stage, when the DOE applies for a license to receive and possess the waste, the underground excavations will cover several tens of thousands of feet. As shown in Fig. 2, they will consist of the shafts, the underground area around the shafts, and part of a waste-emplacement area. In addition, the construction of the surface facilities for initial operation will be substantially complete.

Starting with repository construction, the in-situ testing program will be part of the performance-confirmation program required by the NRC. Included in this program will be the monitoring of the host rock (e.g., the thermal response) and the examination of a number of emplaced waste packages. This performance confirmation program will continue until the end of the waste-retrievability period--that is, for 50 years after the start of waste emplacement. In addition, throughout repository excavation, the properties of the host rock will be observed and measured. At the end of the operating period, the excavations are expected to total more than 600,000 feet. All of the data collected during excavation and the performance confirmation program will be used in the third licensing stage--application for a license amendment to close the repository.

Thus, the in-situ testing during site characterization is but the initial phase of an in-situ testing program that will extend for some 60 years<sup>7</sup>, an in-situ testing during the test stages of repository development will be actually expanded as necessary to support a high level of confidence in findings associated with reasonable

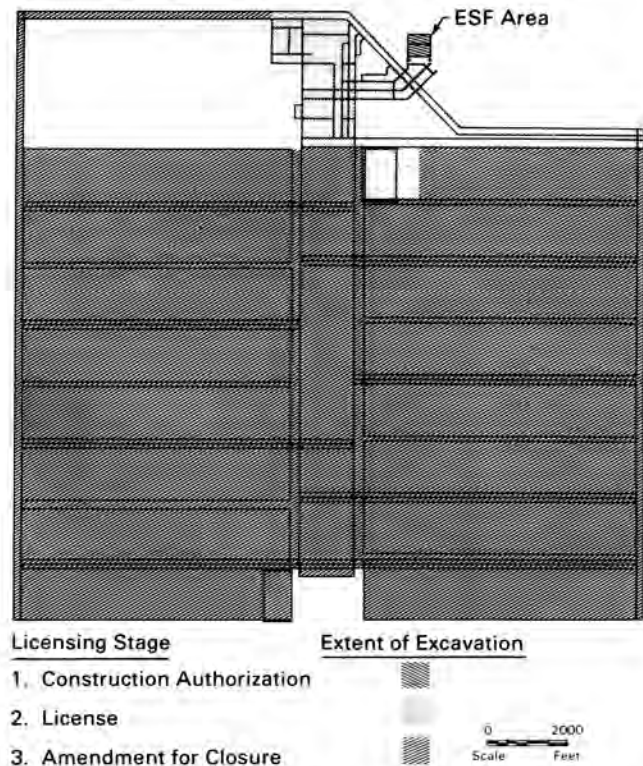


Fig. 2. Extent of Underground Excavation at Different Stages of Licensing for a "Representative" Repository.

assurance. Information obtained from this facility and from surface-based boreholes will provide the basis for the license application.

At the end of site characterization, there will be characteristics and phenomena that are "known" through observation and testing. These include, for example, observed geologic structures and measured rock characteristics at specific locations. There will be uncertainties associated with these "knowns," but they will be quantifiable to a large extent.

There will also be "known unknowns"; these are characteristics and phenomena that can be identified, but are difficult to quantify. Examples are 1) the thermal properties of the rocks within the repository but outside the area of in-situ testing and exploratory borings and 2) the large-scale hydrologic and thermal response to the emplacement of waste. The uncertainties associated with these "known unknowns" are greater than those for the "knowns"; however, reasonable limits can be placed on them.

A final category is the "unknown unknowns." They include characteristics and phenomena that exist but have not been observed or measured or become evident in any way. They could include an undetected fault within the repository location or an unexpected chemical phenomenon that occurs under repository conditions 20 years after the emplacement of waste. Even the identification of these "unknown unknowns," let alone their quantification, is speculative at best. Yet such things are possible; they cannot be completely ruled out. These are the unknowns that will be postulated, but will be virtually impossible to prove or disprove without direct investigation. They may become the most contentious issues in the licensing proceedings. It should be noted, however, that most such unknowns, if they are discovered, can be accommodated by design or engineering measures. In fact, one of the siting guidelines requires a host rock unit that is extensive enough to allow for flexibility in developing the repository.

At each stage in the licensing process, more information will be gained, and the quality of evidence will be improved. The "knowns" and "known unknowns" will increase, and "the unknown unknowns" will decrease. At the time of the license application, after site characterization, the two most significant "unknown unknowns" will be (1) specific anomalous geologic conditions within the host rock of the repository outside the exploratory-shaft facility and (2) the long-term large-scale behavior of the waste package, the repository, and the site, acting as a system. These uncertainties are unavoidable given the constraints of limited exploration and prudent use of funds. The limitations in exploration result, in part, from restrictions imposed by 10 CFR Part 60 and in part from the practical limitations and costs of site characterization.

At the time of permanent closure, the "unknown unknowns" will be substantially reduced. As a result of the performance confirmation program, the quality of evidence will be much higher than at the time of construction authorization.

It is thus clear that there will be a continuing and substantial reduction in uncertainties as more is understood about the site and the performance of the system during repository construction and operation. In contrast, a recent NRC staff paper<sup>4</sup> suggested that the uncertainties will not be

substantially reduced after the license application and that only marginal reductions will occur up to permanent closure. This conclusion does not seem to be consistent with 10 CFR Part 60, as discussed below.

#### REASONABLE ASSURANCE THROUGH THE LICENSING PROCESS

The expected changes in the quality of evidence, and thus in the level of reasonable assurance, as licensing proceeds appear to be compatible with 10 CFR Part 60. Part 60 recognizes that some uncertainties will be significantly reduced only through testing and monitoring during the construction and operation of the repository. For example, much of the testing and monitoring of repository conditions will occur after underground excavation has started; this program of testing and monitoring is the performance confirmation program required by 10 CFR Part 60. This monitoring of actual emplacement conditions will be used to confirm the original design assumptions and will play a major role in reducing the uncertainties associated with repository performance and providing a high level of assurance. If a very high level of assurance were required for the construction authorization, the program of performance confirmation would be an unnecessary redundancy to the licensing process.

The waste-retrievability requirement of 10 CFR Part 60 also acknowledges the existence of substantial uncertainties after construction authorization; without the uncertainties there would be no need for the retrievability requirement. Indeed, it has been suggested<sup>8</sup> that, if the basis for the findings associated with "reasonable assurance" is constant, then the requirement of reasonable assurance at the time of construction authorization and the requirement of retrievability are redundant. This argument notwithstanding, the DOE considers that the retrievability requirement implies, and a realistic approach to licensing a repository requires, that determining reasonable assurance will have different meanings at each stage of the licensing process and thus the requirement of retrievability is a valid one.

To understand what level of understanding of the site the DOE should have at the time of construction authorization, it is important to review the development of 10 CFR Part 60. One of the reasons the NRC requires a licensing proceeding at the end of site characterization is to have an acceptable level of confidence that the repository is licensable before extensive development and a major expenditure of funds occur. As stated earlier, the NRC identified in the procedural portion of 10 CFR Part 60 (published in 1981) that a facility consisting of two shafts and up to 1000 feet of tunnels at a cost of \$25 to \$30 million would represent the upper limit for the "at-depth" portion of site characterization in soft rock (hard rock would cost approximately 30 percent more). Current DOE plans for site characterization in-situ testing appear to meet the suggested investigation level.

As already explained, the initial license application will contain a performance assessment that will demonstrate that the site is suitable for a repository. This assessment will be based on the current understanding of the site and will use bounding assumptions of site conditions to conduct the analyses. It is important to remember that the DOE's license application will be complete and sufficient to meet the requirements of 10 CFR Part 60. Furthermore, the NRC expects<sup>4</sup>

that the DOE will rigorously identify and analyze the uncertainties in repository performance and examine them with respect to the performance objectives. However, reduction of the uncertainties associated with the analyses (e.g., validation of models, variability of rock characteristics) will be a process that spans the entire period of repository development.

10 CFR Part 60 requires the NRC to make a finding of reasonable assurance at the time of construction authorization. The question is, What should be the basis for this determination? A logical approach seems to be that suggested by Roberds et al.<sup>9</sup>: the required demonstration of compliance with the performance criteria can be provided at any step in repository development by

1. Prediction (with inherent uncertainties) of future performance, based on numerical modeling or extrapolation from physical models.
2. Verification of performance, based on the results of monitoring.

On this basis, the required level of demonstration of compliance at the time of construction authorization could be defined as the following:

The initial license application (LA) should demonstrate that, taking into account the site characteristics and the design presented in the LA, there is a high level of confidence that the repository will comply with the performance objectives of 10 CFR Part 60.

The key phrase in this definition is "taking into account the design." The application should be reviewed on the basis of the design. The design will have certain assumptions associated with it, such as the variability of rock characteristics throughout the repository horizon. The validity of these assumptions will be demonstrated during the performance confirmation program.

#### CONCLUSIONS

"Reasonable assurance" is a term used by the NRC to describe the confidence necessary to conclude that the performance objectives of 10 CFR Part 60 will be met. Reasonable assurance includes consideration of a "standard of performance" and the "quality of evidence" provided. Since the quality of evidence increases and the uncertainties decrease throughout the licensing process, the basis for the finding associated with reasonable assurance should also change. In other words, as licensing proceeds, the quality of evidence needed to reach a finding associated with reasonable assurance must increase. Conversely, at the time of construction authorization, the quality of evidence will be much less than that at permanent closure. This concept has not been reflected in current NRC documents<sup>4</sup> but appears to be the intent of 10 CFR Part 60. If the basis for the finding associated with reasonable assurance is constant (does not change

with time), then a licensing review will be unnecessary at the updated-license-application phase and the amendment for permanent closure since reasonable assurance will have been previously obtained. It also follows that if the ultimate level of reasonable assurance is required and provided at the time of construction authorization, then the retrievability requirement is also an unnecessary redundancy.

The DOE has concluded that the application of 10 CFR Part 60 requires the basis for the finding associated with reasonable assurance to change with the phases of repository development. In the early stages of repository development (e.g., initial license application) there will be a larger degree of uncertainty than in the later stages (e.g., amendment for permanent closure). Therefore, the basis for the finding associated with reasonable assurance should change during the licensing process to correspond to increasing levels of confidence.

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